

# Silicon Nitride Ceramics for Structural Components in Avionics and Space

## Introduction

Nowadays, lightweight, stiff and strong materials with a low CTE are highly demanded for structural and optical applications in avionics and space.

Due to the excellent combination of properties, dense sintered (SSN), gas pressure sintered (GPSN) hot pressed (HPSN) or hot isostatic pressed (HIPSN) silicon nitride and silicon carbide ceramics and composites are candidate materials to fulfill design and optical engineers requirements. Truss structures and spiders for telescopes, instrument base plates as well as housings for telescopes and gyros made of silicon carbide and silicon nitride have been approved and got into serial production.

## State of the art

In this paper, state of the art, newly developed grades as well as already validated and successfully tested and used materials will be presented. Properties as well as behavior in ambient and changing atmospheres and temperatures are explained. But these materials are not only suited for components in flying equipment, but also for the secure and contamination free processing of high purity products, for mechanical and chemical engineering as well as for metal forming, foundry industry and for equipment, used for production and testing of electronic components like wafers. Processing routes, dimensions, shapes, tolerances, testing parameters and routines for inspection as well as materials and component properties will be addressed. A lot of R+D work was done with these non oxide ceramics during the past three decades. They so got industrialized and are produced around the world. Components like balls for roller bearings, seal rings for mechanical seals, linings of equipment for mechanical and chemical engineering and electronics as well as burner nozzles, heat exchangers, immersion heater sheaths advanced kiln furniture, wear parts and – more and more upcoming – also armor plates are widely used in many fields of industrial technology.

Tab. 1 Properties of ceramics used for lightweight structures in avionics and space instruments

	Material		Density	Young	CTE	TC	4PBS	Tough
			$\rho$ [g/cm <sup>3</sup> ]	E [GPa]	$\alpha$ [· 10 <sup>-6</sup> /K]	$\lambda$ [W/m·K]	$\sigma$ [MPa]	k1c [MPa·m <sup>1/2</sup> ]
	SiO <sub>2</sub>	ULE	2,21	91	0,03	1	32	2
Silicon nitride ceramics	Si <sub>3</sub> N <sub>4</sub>	FSNI	3,25	310	1,4	25	750	6,5
	Si <sub>3</sub> N <sub>4</sub>	HTC	3,32	310	1,5	85	750	7,5
	Si <sub>3</sub> N <sub>4</sub>	HTCHP	3,34	320	1,5	65	1050	7,5
	Si <sub>3</sub> N <sub>4</sub>	HiPUR	3,21	330	1,3	25	1020	6,5
	Si <sub>3</sub> N <sub>4</sub>	TiN	3,45	350	1,6	25	950	7,5
Silicon carbide ceramics	SSiC	FSC	3,14	430	2,2	145	510	4
	CESiC®	HB	2,95	350	2,3	145	320	3,7
		MF	2,65	249	2,1	121	149	4,6
	SiSiC	90	3,1	380	2,5	140	290	3,5
	SiSiC	80	3,03	360	2,4	150	290	3,5
	SiC	LPS	3,25	410	2,6	90	500	5
	SiC <sub>f</sub> /SiC	CVI	2,6	200	2,5	18	500	15
Various others	B <sub>4</sub> C		2,5	410	4,8	28	500	3,5
	Al <sub>2</sub> O <sub>3</sub>	S Cryst	4	400	6	20	450	4
	Al <sub>2</sub> O <sub>3</sub>	SiCw	3,75	390	5	40	500	8,5

## Silicon nitride and silicon carbide at FCT

FCT Ingenieurkeramik GmbH is developing and producing silicon nitride and silicon carbide materials since about 25 years. Different grades are in production, but also permanent R+D activities are in place in order, to optimize specific properties and generate new grades with improved performance and increased component reliability. This is not only true for the materials side, but also for our processing procedures for the production of ceramic components. Further on, this paper is focused to silicon nitride ceramics.

Now a newly developed family of silicon nitride ceramics is available in even large and complex shaped components. With a CTE of down to <math>1,3 \times 10^{-6}/K</math>, thermal conductivity of up to 85 W/m·K at 20 °C, 4-point bending strength of up to 1100 MPa and the ability to get polished to optical grade mirror surface without coating.

These materials have opened new fields for further application in avionics and space. Such newly developed

Tab. 2 Strength of glued and active brazed silicon nitride

Silicon Nitride to Silicon Nitride		
Braze Area 78,5 mm <sup>2</sup>	Tensile Load [N]	Failure Stress [MPa]
Glue 1	3620	46
Glue 2	4211	54
Braze 1	6525	83
Braze 2	1177	15
Braze 3	5828	74
Braze 4	5360	68

ceramics in combination with fabrication technologies, allowing also rather large, lightweight and highly complex designed structures with high precision in design and smooth surface roughness show potential, to outperform the actually mainly used silicon carbide grades, and – more-

### Karl Berroth

FCT Ingenieurkeramik GmbH  
96528 Rauenstein, Germany

E-mail: k.berroth@fct-keramik.de  
www.fct-keramik.de

Tab. 3 Thermal conductivity of various silicon nitride grades and SSiC

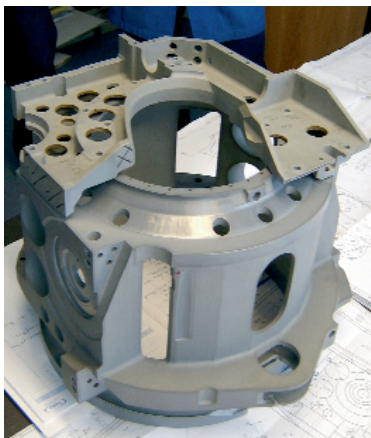
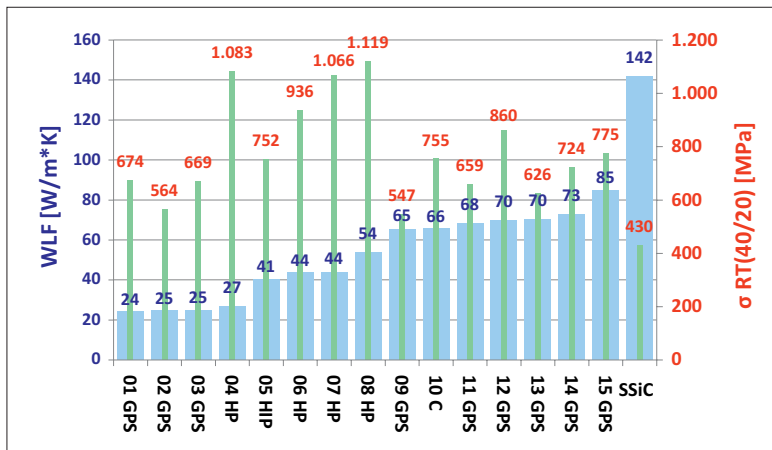


Fig. 1 Housing structure (l.) and final assembly of an avionic reconnaissance telescope camera (r.)

over with silicon nitride →, add a new material with very promising properties and application options and alternatives to both, metals, composites and ceramics in aviation and space instruments.

Components made of these materials are available on a commercial base with diameters up to 500 mm and length up to 1300 mm. The material thickness ranges from 0,125 mm up to 70 mm. Major properties of those silicon nitride and silicon carbide grades are presented in Tab. 1 in comparison with

materials which are used in avionics and space structures.

## Connecting procedures

Besides the materials and processing properties, also the need of connecting ceramic components with each other or with other materials like metal, composites or plastics is of major importance, because not all shapes and dimensions could be realized in monolithic ceramics.

Whenever production facilities come to a border or if the geometric struc-

ture requires to separate it into two pieces for being able to realize the requested geometry, a connecting procedure of ceramic components is necessary to have. FCT therefore also has investigated means of connecting

- ceramic with ceramic components
- ceramic with metal components
- ceramic with plastic components

with a focus on ceramics with ceramics. Different approaches are to be detailed:

- gluing
- brazing
- shrink fit
- clamping
- screwing.

For lightweight structures, most important is gluing and brazing ceramic to ceramic components. This facilitates to produce highly complex and large structures, using smaller individual parts and by means of brazing, also repair work gets possible for structures with defects like chips, cracks or wharpage.

Tab. 2 shows results with two glues and 5 different active brazes. Two cylindrical samples were glued/brazed together at two ground faces and then tested under tensile load until fracture. For organic glues, the problem of embrittlement at cryogenic temperatures has to be solved by specific glues. For active brazes, the temperature range and more likely the activator elements have to be adjusted in order to reach an activation and binding at lowest possible temperature.

## Silicon nitride with high thermal conductivity

In order to overcome the lack of high thermal conductivity, which for standard grades of silicon nitride is poor, compared to silicon carbide, a R+D project was started at FCT in cooperation with customers to develop grades with increased thermal conductivity, keeping the high strength and fracture toughness as well as the very low CTE. As target, a value of at least 70 W/m·K was set at a 4-point bending strength of at least 700 MPa. The production processing has to be feasible with the request of the ability to make tubular structures with more than 1 m in length and also complex 3-D structures for beam connector elements. State of the art now is shown in Tab. 3. Several grades have been achieved, densified by either uniaxial hot pressing or gas pressure sintering with thermal conductivities

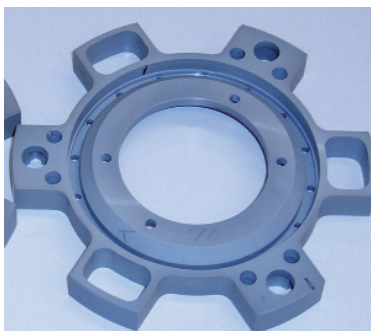


Fig. 2 Spider base for small satellite made of Si<sub>3</sub>N<sub>4</sub>

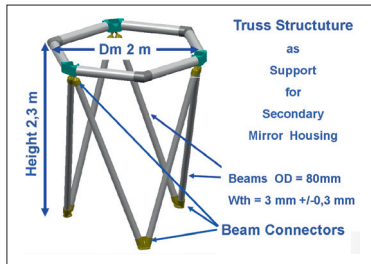


Fig. 3 Principle of truss structure

from 45 – 85 W/m·K. The lower values reached by hot pressing show very high strength values up to 1100 MPa. The gas pressure sintered grades reach up to 85 W/m·K at a strength level of 750 MPa and still high fracture toughness. CTE is still at a very low value, much lower than the ones for silicon carbide. Some grades are already available as components, other are still only in lab scale sample size.

With the company's grades, – already produced since many years – and the newly developed, optimized and partially qualified for avionics and space, a new material family of silicon nitride grades is available on a commercial base for reasonably large, highly complex structural parts. They offer significantly increased mechanical performances in regard to strength and fracture toughness compared to silicon carbide and glass ceramic materials, which may also help to get much higher reliability in components. Another parameter is the CTE of silicon nitride grades which is always much lower than all the ones of silicon carbide grades and all other high strength and tough ceramics (Tab. 1).

## Avionics and space experience

Since about years we started to produce and supply ultra light weight highly stiff structures with very low CTE silicon nitride ceramics for airborne reconnaissance telescope camera systems (Fig. 1).



Fig. 7 Nuts and bolts with thread made of silicon nitride and silicon carbide

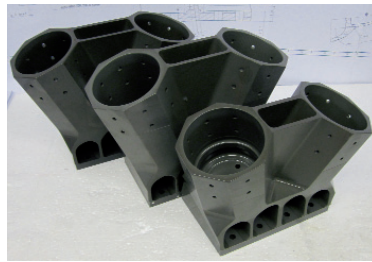


Fig. 4 Beam connectors and beam ends

Since 2006 FCT is in progress to qualify silicon nitride also for space telescopes (Fig. 2). Some facts are described in cited literature. Qualification of scale 1 preflight components was reached in 2010/2011 and since then FCT is qualified supplier for space structures.

Since 2011 FCT is producing and supplying flight model components for the first space telescopes having a silicon nitride truss structure (Fig. 3). In 2012 FCT has successfully completed this by delivery of all components for this rather large structure of an earth observation satellite. The truss structure is made of specific lightweight beams and beam connectors (Fig. 4–5). The integration into the space instrument is ongoing. Also weight saving is the replacement of steel balls in ball joints by silicon nitride (Fig. 6). It also prevents corrosion.

Mainly in high temperature applications and in corrosive media, the use of bolts and nuts with threads have helped to facilitate highly effective and reliable installations and fixations (Fig. 7). Here FCT replaces steel, titanium or other metals and polymers. Also for high temperature engineering we do quite a bit of tubes, beams and profiles with silicon nitride and silicon carbide which are highly stiff and lightweight – with low thermal mass –, are thermal shock resistant and can be used up to temperatures of 1300 °C for silicon nitride and 2000 °C for silicon carbide (Fig. 8).

In some applications FCT replaces Ni-based alloys like HASTELLOY e.g.

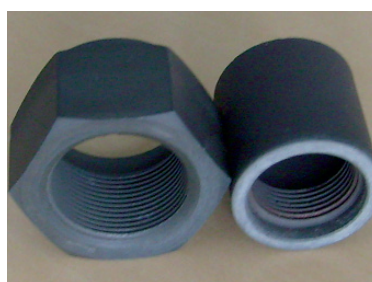


Fig. 5 Testing set up for silicon nitride beams and connected beams for satellite truss structure

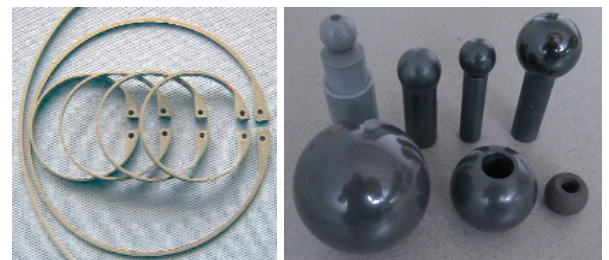


Fig. 6 Silicon nitride spring rings (l.) and ball-and-socket joint (r.)

in high temperature applications running up to 1300 °C with very strong thermal, chemical corrosion and creep requirements.

Another application is in flying electronics specifically for highly mechanically and thermally stressed substrates. Here, mainly disc and plate like shapes are required with diameters up to 420 mm and thickness ranging from 0,125 up to 2,0 mm. These discs and plates typically have to be ground and lapped or even must be polished.

With hot pressed grades, direct polishing to optical grade surface finish



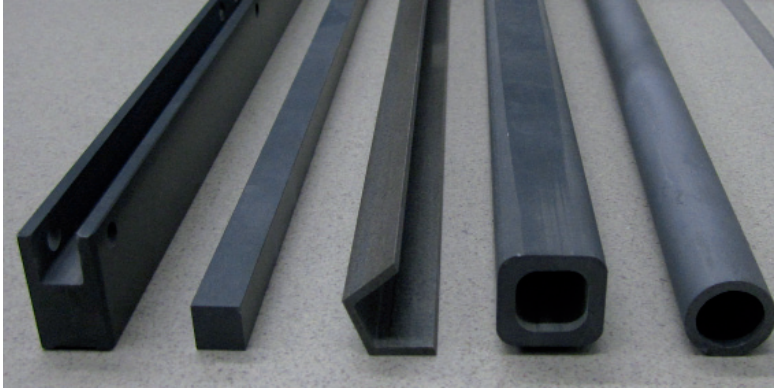


Fig. 8 Tubes and profiles of SSiC and  $\text{Si}_3\text{N}_4$

without any coating can be achieved. This is caused by the fully densified, fine grained, homogenous and void free microstructure of the silicon nitride. Silicon carbide however always shows micro pores and/or carbon particles as imperfections and therefore requires coatings when it is used for mirrors.

## Conclusions

Silicon carbide ceramics in different grades are already widely used in avionics and space. Silicon nitride is new for this application. Although it shows some properties like mechanical strength and fracture toughness as well as a very low CTE – much lower than for silicon carbide grades – it has potential, to outperform

some of the up to date used materials. One mayor constraint is – up to now – however the limited size of components, which should be typically less than 1,5 m in length and less than 700 mm in diameter. And additionally, it was never validated and used for space instruments.

But finally, one grade of silicon nitride is now validated and qualified for the truss structure of a satellite telescope and so other components for flight instruments can be produced in the future. The truss components have passed the required proof tests and their integration into the satellite is in progress.

On the other side, avionic reconnaissance cameras with housing structures – made of a second grade of silicon nitride – are meanwhile suc-

cessfully flying on jet airplanes since about at least 5 years now without failure.

Components of silicon nitride and silicon carbide according customer design are available at FCT Ingenieurkeramik GmbH. For further information, please contact us.

## Acknowledgement

Thanks to *ThalesAlenia Space*, France, and *CNES* for financial support in the development of “Silicon nitride with high thermal conductivity”.

## References

- [1] Berroth, K.; Devilliers, G.; Luichtel, G.: Silicon nitride for lightweight stiff structures for optical instruments, Proceedings of SPIE conference on OPTICS + PHOTONICS conference, Paper number 7425–26
- [2] Berroth, K.: Silicon Nitride and Silicon Carbide Ceramics for structural Components in Avionics and Space. Proceedings of 12th European Conference on spacecraft Structures, Materials & Environmental Testing, March 2012, Nordwijk, Paper s3d2
- [3] Devilliers, Ch., Lasic, T.; Boban, D.; Cornillon, L.; Tanzilla, D.; Autzaid, S.; Berroth, K.:  $\text{Si}_3\text{N}_4$  ceramic application, development and qualification results for truss structure of large space telescope. Proceedings of ICSSO 2012, Internat. Conference on Space Optics 2012